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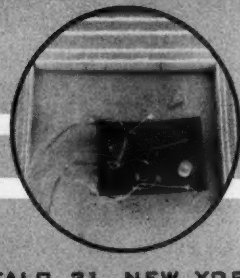


research trends

CORNELL AERONAUTICAL LABORATORY, INC., BUFFALO 21, NEW YORK

PHYSICS UP IN THE AIR . . .

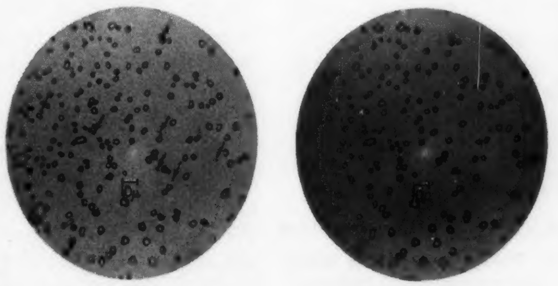
Research in Atmospheric Physics Covers Broad Scientific Front

by DR. JAMES W. FORD

"Atmospheric Physics" will not be found as the title of any course in a college curriculum. Yet the term aptly describes that scientific activity which brings meteorology, cloud physics, propagation of electromagnetic energy, atmospheric electricity, and such specialities as weather modification into an effective, working relationship.

Effort in atmospheric physics, one of the Laboratory's oldest technical program areas, has been centered on basic research. Much of the basic information which results finds ready application, however, primarily because contemporary aeronautics is reaching so deeply into our store of scientific knowledge.

CAL's research activity on physics of the atmosphere has a provocative way of revealing little-known facts about our atmosphere and its constituent materials. For example, everyone "knows" that water freezes at 32°F. Yet the tiny spheres shown in Fig. 1 — approximately one micron (a thousandth of a millimeter) in diameter — were liquid water droplets at –62°F. The experiment which yielded this photograph was performed during an investigation of the factors controlling the formation of jet contrails. This investigation is one of several interrelated studies in atmospheric physics being conducted in the Laboratory's Applied Physics Department.



(a) (b)

FIG. 1 — Ten (microns) = 0.0004 inches. Minute particles collected from a laboratory contrail. Temperature was –62°F, altitude 24,000 feet. During the interval between exposures (a) and (b), the particles indicated by arrows evaporated in an ice-saturated atmosphere, indicating that they were liquid water.

Controlling Contrails

Contrails — the vapor trails left by jets flying at high altitudes — have an undesirable way of pointing out airplanes in the sky. Both the Air Force and the Navy, therefore, share an easily understood interest in their control, and both agencies are sponsors of current CAL work in this field.

As a part of the contrails program, CAL has been conducting experiments with liquid droplets at subfreezing temperatures. The existence of liquid droplets at such temperatures has an important bearing on the contrails problem. Jet airplane contrails not only look like ice crystal clouds, but Signal Corps investigations have produced photographs of ice crystals collected from contrails. "Sun dogs" — phenomena ordinarily seen in conjunction with solar halos and which indicate the presence of ice — also have been observed in contrails.

The fact that liquid droplets do exist at subfreezing temperatures has been explained in theoretical terms. Some recent experiments with droplets as small as 10 microns (0.0004″) in diameter, and at temperatures as cold as –40°F, have confirmed the theory. The CAL picture, however, is the first direct evidence that liquid water can exist at even colder temperatures. It is estimated that a droplet's lifetime at –62°F may be some 160 seconds.

We know that ice will sublime, that is, pass directly from the solid to the gaseous state without appearing as liquid. It has been thought that the reverse might be possible: water vapor at subfreezing temperatures might condense directly to the solid state in the presence of ice crystallites, without ever existing as liquid water.

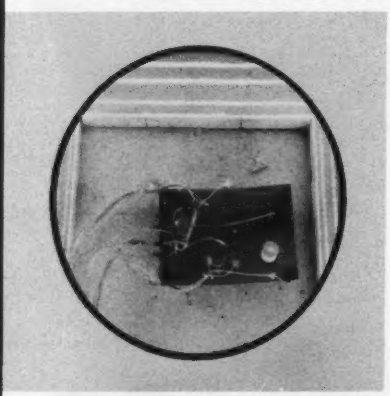
Because the control of contrails depends greatly upon the physical form in which water appears, the search for liquid water at temperatures at which contrails will form became a major feature of the research program.

To investigate this point, we first burned small

FIG. 2 — Goniometer constructed to measure the light-scattering characteristics of typical ice crystals. Inset photo shows model ice crystal mounted for measurement.

quantities of jet fuels in a typical deep freeze cold box. Preliminary results were encouraging. They clearly proved the existence of the liquid-water state in contrails. Results also showed the types of ice crystals which predominate in contrails formed under a variety of temperature and humidity combinations.

Knowledge of these crystal forms made possible careful measurement — on a larger-than-life basis — of the light-scattering characteristics of typical crystals. From this information it was possible to evaluate the visibility of a real contrail, since it is the sky light and direct sunlight scattered by its ice crystals that make a contrail visible. A special goniometer (Fig. 2) was constructed for such measurements. It functions properly in temperatures as cold as −85°F — one of the rigid requirements for such a mechanism. The outsize model ice crystal used in these experiments was grown by a molding technique which eliminated internal air bubbles that could cause too much light scattering.



THE COVER

Thermal problems being encountered by high-temperature electronic equipment are under attack at CAL in a research program sponsored by the Bureau of Ships. These problems include both thermal design of individual parts and cooling of assemblies. Here an experimental audio amplifier is operating at an ambient temperature of 640°C (about 1200°F). The amplifier operated successfully at 500°C for 20 consecutive hours before the temperature was increased; operation contained at the elevated temperature for two hours. Clearly shown in this infrared photo is the thermocouple instrumentation. The amplifier is enclosed in a kiln, which creates the high-temperature environment; the white lines on the sides of the kiln are the heating elements. Results of this research will be applicable to problems of high-speed aircraft and missile re-entry.

Tests in Altitude Chamber

Tests were next carried out in CAL's altitude chamber. Here a full spread of pressure, temperature and humidity values could be set up to simulate any desired flight condition.

A quick comparison between some earlier Air Force data and recent CAL findings can be found in Fig. 3. These graphs relate altitude (pressure) and temperature to the likelihood of contrail formation. The legends "never," "always," and "possible" mark those atmospheric regions in which contrails never form, always form, or may form, depending upon the amount of moisture in ambient air.

The CAL findings demonstrate that whereas contrails with a small content of water can be seen in bright sunlight with clear skies, under cloudy conditions only contrails of much greater water content can be detected.

Thus we have introduced the new criterion of visibility into the technique of contrail forecasting. This criterion is an important one. Knowing it, a pilot may take advantage of the camouflage aspects of a high-overcast sky and fly without discovery, whereas his contrail would surely be seen if the sky were clear and blue.

Cloud Droplet Sizing An Important Study

In fundamental cloud physics studies, the distribution of droplets according to size is an index of the processes of cloud growth. For example, the time history of a cloud's drop-size distribution may show whether droplets grow primarily by taking the water from droplets smaller than themselves (the evaporation-condensation mechanism) or whether physical contact predominates (the growth-by-collision process).

Data about droplet sizes is used in developing aircraft de-icing systems. Here a knowledge of both the water content of an icing cloud and the distribution of that water among different-sized droplets is needed. Size is important because it determines the aerodynamic behavior of droplets and thus the likelihood of droplets striking the airplane and freezing.

Several different instruments have been used to gather such data, among them the Airborne Disdrometer (Distribution-of-Drop-Size Meter) developed by CAL for the Aeronautical Research Laboratory of Wright Air Development Center (Fig. 4). The Disdrometer recently was flown by WADC's Severe Weather Flying Group in an icing investigation. It will be used shortly by airborne weather-radar specialists to measure drop-size distribution in clouds. These measurements will be compared with radar echoes from the same clouds in order to calibrate the radar equipment.

The main element of the Disdrometer is a sharp-nosed, cylindrical structure with an axial hollow through which droplets pass during flight. On one side, the cylindrical wall contains an optical system which illuminates a very tiny volume (less than one-quarter cubic millimeter) on the instrument's axis. A droplet passing through that spot scatters light, the amount depending on droplet radius squared, to a photo-electric tube in the wall opposite. As droplets flash through the illu-

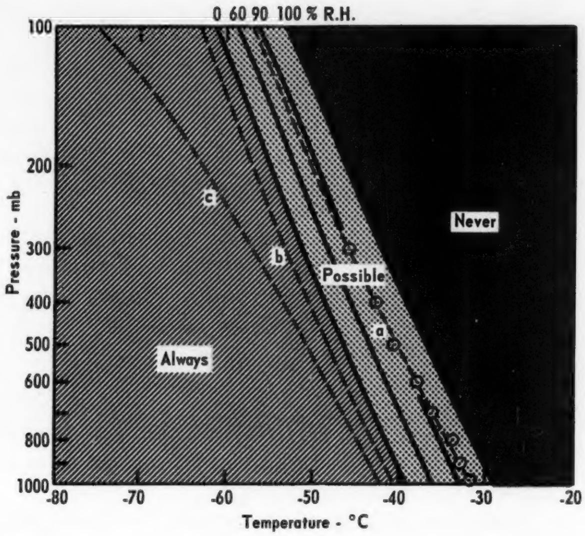


FIG. 3 — Contrail detection as a function of ambient pressure, temperature and relative humidity, and of trail liquid water content. Solid lines were taken from Air Force data. Curves a, b and c are based on improved CAL data. Curve c shows that any contrail viewed under conditions of poor visibility must have a higher water content than one seen under conditions of good visibility.

minated volume, the output current pulses from the phototube are classified according to amplitude and counted. The cycle of amplitude readings is such that every two seconds a complete cumulative distribution is recorded. A unique and particularly valuable feature of the CAL instrument is that it in now way changes the shape of drops it measures.

"More Sun for Buffalo" Under Study

To most people, the term "weather modification" implies "rain-making" — the artificial stimulation of rainfall. Equally interesting, but less well known, are two types of weather modification under investigation at CAL. These have had the project titles: "More Sun for Buffalo" and "Freeze." The purpose of the projects is to change unattractive — even dangerous — weather situations into more pleasant ones.

In "More Sun for Buffalo," cloud dispersal techniques, employing the cooling effect of dry ice, will be used to eliminate those relatively thin stratus cloud decks (1000-2000 feet thick) which customarily hang over Western New York during the winter months.

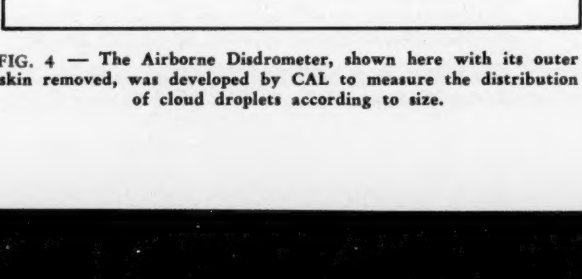


FIG. 4 — The Airborne Disdrometer, shown here with its outer skin removed, was developed by CAL to measure the distribution of cloud droplets according to size.

This cooling procedure, of course, will convert the cloud moisture to snow. However, since the clouds have such a small water content they will produce only a barely detectable snowfall.

These clouds, despite their relative thinness, prevent direct sunlight from reaching the ground. They are primarily responsible for the fact that Buffalo enjoys only about 33% of the winter sunshine which it might otherwise have.

According to calculations by atmospheric physicists at CAL, five or six pounds of dry ice per mile of flight path, dropped into such stratus clouds, will open a slot a mile or more wide. Exact results will depend upon circumstances of temperature and the water content of the clouds. The slot will, of course, move downwind with the cloud that contains it; if the flight path is properly oriented, the opening will pass over the area where the sunshine is desired.

The distribution of dry ice by airplane is a relatively straightforward and inexpensive procedure. The experiment has been designed and preliminary meteorological studies and tentative flight plans have been prepared. Before seeding can take place to make more sunshine,

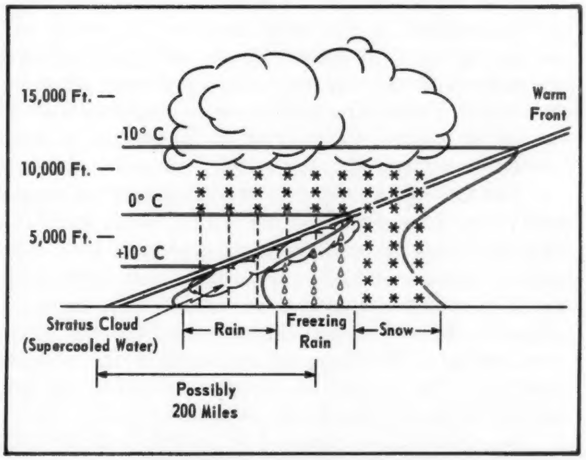


FIG. 5 — Cross-section of a warm-front freezing-rain situation typical of the Western New York area.

certain legal and financial matters must be settled. Some local financial support for the project has already been promised.

Project "Freeze" Another Physics Activity

A second weather situation characteristic of winter in the north central and northeastern states is the occurrence of freezing rain. Buffalo experiences such rain two or three times each winter. Glaze ice coats airport runways and ramps, as well as highways, with resultant danger to pilots, drivers and passengers. In view of the hazard to safety, CAL undertook a program known as Project "Freeze," which derives its name from the freezing rain phenomenon.

Associated with the well defined and easily predictable meteorological situation sketched in Fig. 5, freezing rain depends upon the ability of water to supercool, that is, to remain liquid at temperatures colder than 32°F.

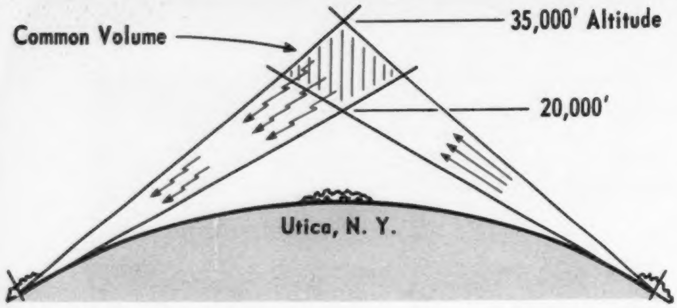


FIG. 6 — CAL is investigating the phenomenon of long-distance transmission of UHF radio signals. A 28-foot antenna and sensitive receiver pick up that very small part of the signal which is scattered in the troposphere. The 915-megacycle transmission originates nearly 400 miles away.

which is colder than 32°F, it is forced upward and goes into a precipitating state. Its rain then supercools while falling through the lower, cold stratum. Unable to remain liquid upon contact with subfreezing surfaces — ground, road, automobiles, trees, power lines — the rain immediately freezes to glaze ice and creates the hazardous situation with which most of us are familiar.

In its supercooled state the rain is ripe for seeding — for conversion to the solid state — by means of a nucleating agent. It is also ripe for sub-supercooling — for conversion to ice particles — by a cooling agent such as dry ice. Conversion of the rain to ice particles clearly would be a good move since the hazard of glaze ice would be eliminated.

The seeding technique most often employed requires generating a smoke of silver iodide crystals and lifting that smoke on an atmospheric updraft to a level where seeding can occur. Although one of four experiments at CAL using ground-based silver iodide generators showed a hint of success, it was found that the typical meteorological situation did not contain the necessary updrafts. The method was dropped, therefore, in favor of one employing dry ice as a coolant.

Because airborne dispersal of dry ice, as in the stratus seeding case, might subject the airplane to untoward icing dangers, we have turned to rocketry as a means of dry ice dispersal. Relatively small, self-consuming rockets, now under design, will carry dry ice to altitudes of a few thousand feet — generally to the top of the cold air layer — where the freezing agent will be dispersed by a small explosion. The winter of 1958-1959 should see some action with these units.

CAL Studies Radio Propagation

Sometimes the atmosphere's characteristics are manifested in ways more subtle than contrail displays or freezing rain storms. One such way is the "scatter" propagation of electromagnetic energy.

To visualize this phenomenon, imagine yourself driving along a highway at night in hilly country. Although a rise of ground may prevent you from seeing an oncoming car, the glow of its headlights proves its presence; the light is scattered in your direction over the hilltop by means of air molecules and dust particles in the atmosphere.

In similar fashion, electromagnetic radiation in the range of radio frequencies is scattered by inhomogeneities in the atmosphere, presumably parcels of air which are created by turbulent action and which have differing dielectric, or refractive index, values. The experimental set-up used by CAL to study the mechanism of the scatter of radio energy in the troposphere is shown in Fig. 6.

While the energy is scattered by all portions of the atmosphere through which it passes, the volume of special importance to us is one which is common to the beams of both antennas. That volume lies over mid-state New York at an altitude over 20,000 feet.

Radio energy — at a 915 megacycle per second frequency — is scattered from the common volume and ultimately reaches our receiving antenna. It is analyzed in a variety of ways in attempts to learn more about the way in which scattering occurs.

Variations in signal intensity with time are strikingly rapid on occasion; at other times less activity may appear. The passage of an airplane through the common volume yields a high peak of received energy. During the thunderstorm season of 1957 we identified strong forward scattering from the ionized paths of lightning strokes.

After almost a year of data gathering, some definite patterns are beginning to emerge. Particularly important, we feel, is a close relationship between the scatter signal's "fading" characteristic and wind shear, that is, the variability of wind speed with altitude, within the common volume.

CAL is one of several laboratories engaged in a concerted attack on radio scatter. As a result of this effort, hitherto accepted theories may need revision.

Significance of Studies

The cloud physics, instrumentation, and electromagnetic propagation activities at CAL are significant in that each offers an answer or promises a forthcoming answer to definite problems posed by a sponsor or by the community. Contrail studies have obvious military applications. "More Sun for Buffalo" and "Freeze" have definite economic and social advantages to the community. Civil, as well as military communications will be improved through application of CAL's tropospheric scatter studies. Even without such applications — and they are manifold — man's constant search for knowledge would lead scientists to continue probing the physical world above us.

Editor's Note: In the winter issue of *Research Trends* Dr. Ford will discuss research in atmospheric electricity and auroral propagation.

REPORTS

"We Can Have More Winter Sunshine in Buffalo," Chapman, Seville; Buffalo Business, Vol. 32, No. 3, March, 1957.

"A Forward-Scattering Optical Disdrometer, WADC TR 57-561, Hendrick, Roy; Aug., 1957.

"UHF" Forward Scatter from Lightning Strokes," Bauer, Louis; Flood, Walter; Proceedings of the IRE, Vol. 45, No. 12, Dec., 1957.

"A Lab Study of Contrails," Pilie, Roland; Jiusto, James; Journal of Meteorology, Vol. 15, No. 2, April, 1958.

DOPPLER RADAR . . . and the TORNADO PROBLEM

Damage Caused by Tornadoes May be Mitigated with New Warning System

by FREDERICK S. WOOD

Photograph Courtesy of U.S. Weather Bureau

Tornadoes — among the most dreaded of all weather phenomena — have relentlessly assaulted life and property in midwestern and southwestern United States. Year after year the destructive whirling winds, accompanied by their "funnel-shaped" clouds, have struck with savage fury all that lay in their paths. Until recently there has been no dependable, accurate detection system that could warn residents either to flee or to secure their property in the about-to-be-ravaged areas.

In June, 1957 a trailer housing a new type of tornado detection system was set up at the Airport Weather Bureau Station in Wichita, Kansas. This system incorporated the use of Doppler radar, which measures the radial velocity of moving targets. Technically known as the Doppler Radar Tornado Warning System, it was developed by Cornell Aeronautical Laboratory for the U.S. Weather Bureau.

In Wichita, Weather Bureau personnel continued the field testing begun earlier by CAL in Buffalo. No tornadoes were detected during this season, although some were unofficially reported in the area. CAL's theoretical calculations indicated, however, that the system should respond to local tornadic disturbances.

Early in the Spring of 1958 the equipment was set up at Wichita Falls, Texas. Past experience indicated that a tornado was most likely to occur in this area in the Spring.

On April 2, 1958 an approaching storm was detected on the pulse radar. The Doppler radar operator started to scan the storm area. He detected many low frequency Doppler returns from the hail and rain which preceded the storm center. Then, for the first time, he heard among the other returns a high-pitched note which indicated the presence of a very high velocity. Shortly thereafter a tornado struck Wichita Falls, killing one person and causing hundreds of thousands of dollars damage. A recheck of the tape-recorded signals later showed that velocities of 280 miles per hour had been present in the tornado.

In an attempt to follow the seasonal changes in the tornado belt, the Weather Bureau returned the radar trailer to Wichita, Kansas, in May, 1958. On June 21 the Doppler set detected and tracked a tornado which struck the town of El Dorado, Kansas, about 35 miles northeast of the radar site. The recorded data revealed that wind velocities had reached 205 miles per hour.

At last the Doppler radar, which had been under study for some two years, had been proven practical as a tornado detection device. This successful development brought with it hope for mitigating some of the severe damage caused by tornadoes.

Distinguishing Feature of Tornadoes

A distinguishing feature of tornadoes is the presence of high-velocity winds. These winds are believed at times to exceed 400 miles per hour within their characteristic "funnels." They generally carry considerable rain, occasional hail, and debris from the ground.

During 1957 over 1600 tornadoes and funnel clouds were reported to the Weather Bureau Office of Climatology. Of this number nearly 1000 actually touched the ground. While some of these caused no damage, others wrought considerable havoc. In all, 154 lives were lost in 14 different situations.*

*"Tornadoes During 1957," by R. G. Beebe, *Weatherwise*, Vol. II, No. 1, Feb., 1958.

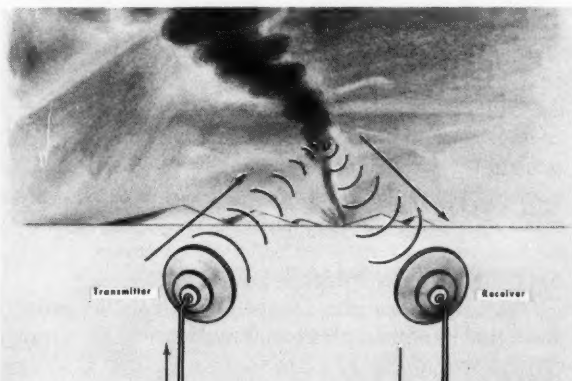


FIG. 1 — Doppler radar as applied to the tornado warning project.

Other Limitations in Tornado Detection

The weather conditions necessary for the formation of a tornado have been determined only in the most general terms. Until recently, the Weather Bureau has been able to ascertain only when these conditions are present, over what area they extend, and how long they will persist. When tornadic weather conditions are present meteorologists, whenever possible, maintain close surveillance over cloud formations and movements with pulse-type radar equipment. Many Weather Bureau stations, particularly in the midwest, are equipped with such installations.

Heavy-weather areas can be pinpointed from the size and intensity of the display on the pulse-radar scope. Oftentimes displays have been compared with visually observed tornadoes. As a result, certain radar-scope patterns have been associated with tornado activity. However, there is no way to determine from the scope presentation alone whether or not a tornado is present or is forming in these areas. Moreover, if a tornado were present, the internal wind velocity would not be indicated.

When appropriate conditions are present the Weather Bureau issues "tornado alerts." These alerts quite frequently cover large areas, sometimes extending over several states. Most of the tornadoes detected in the past were spotted and followed by visual observation.

Echo Characteristics Must Be Recognized

Identification of an object by radar depends upon recognizing certain echo characteristics or "signatures." These signatures take on many forms, depending upon the target and the type of radar being employed. With a pulse-type weather radar the signatures are presented on a plan position indicator (PPI) as a map-like display showing the range, direction, density, and relative size of the target. With Doppler radar the velocity of objects, such as the moisture and debris carried by the vortex winds, can be measured directly.

The Doppler principle was discovered by Austrian physicist Christian Doppler during the early part of the 19th Century. As applied to sound, the Doppler principle explains why the pitch appears to change when the distance between the sound source and listener is changing. A familiar example is the apparent change in pitch of the whistle of an approaching train. The Doppler effect is applicable not only to sound, but to all types of wave motion, including light and radio frequencies.

Applying Doppler Principle to Radar System

Application of the Doppler principle to radar is illustrated by the simple continuous-wave (CW) arrangement shown in Fig. 1. Here an unmodulated CW signal is sent out by the transmitter and reflected back from a moving target, in this case a tornado.

As the target moves, the signal returned shifts in frequency; it will be higher or lower depending upon whether the target is moving toward the transmitter or away from it. The amount of the shift depends upon both the velocity of the target and the carrier frequency of the transmitter. This returned signal is mixed in

FIG. 2 — **Transmitting and receiving antennas get final checkout prior to use. Inset shows author at operating position inside trailer.**

the receiver with a sample of the transmitted energy. The resultant beat note, known as the Doppler frequency, is extracted and amplified to constitute the receiver output. This Doppler frequency is generally in the audio range. Since the signals returned from fixed targets are not shifted in frequency, they do not give rise to any receiver output.

System Proposed for Tornado Detection

In 1956 CAL conducted an internal research program to investigate the application of Doppler radar to the study of weather phenomena. As a result of this study CAL proposed using a Doppler radar system for tornado detection. Subsequent interest of the U.S. Weather Bureau led to contractual arrangements with CAL for the delivery of an experimental Doppler radar to be used during the 1957 tornado season.

The complete system was built around a surplus Doppler radar set, part of a Navy carrier landing system donated by the Navy to the Weather Bureau for this project. CAL modified this equipment to make it suitable for detecting tornadoes.

The carrier frequency of the radar is approximately 10,000 megacycles. From the standpoint of atmospheric attenuation, a lower frequency might have been preferrable for the application. However, the availability of the Navy equipment, plus the desirability for quick delivery of the complete unit, dictated its use.

At X-band frequencies the Doppler shift is approximately 30 cycles per second for every mile per hour of target radial velocity. Since the wind velocities of tornadoes extend from about 100 to 500 miles per hour, the Doppler spectrum covers a range of approximately three to 15 kilocycles. Use of a lower carrier frequency would, of course, result in a lower frequency spectrum.

The transmitter consists of a CW magnetron whose output is fed through waveguide to one or two six-

foot antennas. A very small part of the transmitted energy is fed to the receiver, where it is compared with the reflected signal.

After the transmitted signal is reflected back from the target it is picked up by the second antenna and applied to a balanced crystal mixer. Here it is modulated by the reference signal from the transmitter. The output of interest from the mixer, i.e., the Doppler frequency, is then amplified and fed either to a speaker for aural monitoring or to a tape recorder for a permanent record. From the operating position in the trailer (Fig. 2) the operator is able to orient the antennas simultaneously in both azimuth and elevation, as well as to control the electronic operations.

With the present experimental unit, signals are returned from all moving targets in the antenna beam. They are particularly strong from such near-by objects as automobiles, birds, rain, or hail. Many times this "local interference" is strong enough to mask returns from distant targets. Such is often the case with a tornado, which, as a general rule, is preceded by rain and sometimes hail. Future radars should be able to eliminate this "clutter" by using range gating and pulsed Doppler techniques. Use of these techniques would also allow a substantial increase in range capability, commensurate with other weather radars now in use. The range of the present experimental unit is limited to about 50 to 75 miles under favorable conditions.

Since the Doppler set uses an unmodulated CW signal it cannot provide range information. This deficiency, however, is of little importance under the present mode of operation for range data are derived from pulse radar equipment.

Through continued experimentation, the Weather Bureau has discovered other applications for the Doppler equipment. Information concerning the fall velocities of precipitation has been gathered by pointing the antennas at an elevation angle of 90° during rain and hail storms.

Analysis of tape recordings made during a hailstorm revealed Doppler returns of several different frequencies. Meteorologists have theorized that this phenomenon may be the result of hailstones being formed in discrete size categories and having fall velocities that vary according to size.

Areas of Possible Future Investigations

Modifications of the Doppler system will probably continue to be made in order to increase its applicability to tornado detection. Earlier research has earmarked several areas of possible future investigations. By incorporating in the radar the necessary circuits to determine sensing, or direction of motion, the presence of updrafts and downdrafts — a prerequisite to the formation of large hailstones— could be ascertained during periods of precipitation.

Another area of future Doppler work might include the use of a "Doppler adapter" to be used in conjunction with the radars now used by the Weather Bureau. This adapter could possibly be added to a standard pulse set to permit the extraction of Doppler information. It is conceivable that such information, along with meteorological data from other radar and weather stations, could be fed into a computer. The location of the tornado would be automatically pinpointed and its path predicted. With such an arrangement a relatively inexpensive tornado warning system could be provided for the country's most critical tornado areas.

ABOUT THE AUTHORS

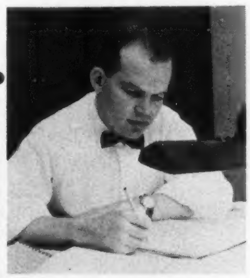
Both the ocean depths and the physical world above us have been research targets for DR. JAMES W. FORD, Assistant Head of the Applied Physics Department. Dr. Ford aided in developing instrumentation for an underwater television survey made of the atomic bomb blast area around Bikini in 1946. In 1951 he stepped into the atmospheric physics program at CAL with responsibility for a study of the earth's electrical field. Since then he has played an active part in all of CAL's atmospheric physics research.

Dr. Ford received the B.S. and M.S. degrees in Physics from Oberlin College and the Case Institute of Technology. In 1940 he was awarded the Ph.D. degree in Physics from Pennsylvania State University.

For three years he worked as research physicist for Spencer Lens Corp. (now American Optical Co.). He joined the Curtiss-Wright Research Laboratories in 1943 as a research physicist in the Physics Department.

At CAL he has served as Head of both the Atmospheric Physics Section and the Applied Physics Branch of the Physics Department. He was named to his present post one year ago.

He is a member of the American Meteorological Society, the Optical Society of America, Sigma Pi Sigma and Sigma Xi.



FREDERICK S. WOOD, Electronics Engineer in the Weapon Systems Design Department, several years ago assisted in a CAL project which investigated the use of Doppler radar to observe weather phenomena. When it was determined that such an application was feasible, Mr. Wood subsequently became project engineer of the Tornado Warning Radar Project, conducted by CAL for the U.S. Weather Bureau.

During the summer of 1953, Mr. Wood was employed as a technician in Sylvania's Advanced Development Laboratory in Buffalo, N. Y. After receiving a B.S.EE. degree from the University of Buffalo in 1954, he joined CAL as a member of the Test Section, then part of the Development Division. He has remained with that group, which has subsequently been made a part of the Weapon Systems Design Department.

Testing missile components and performing pre-flight checkouts were some of his early assignments. His background includes four years experience with the Lacrosse missile system and other CAL developments which have advanced to the prototype stage. He is currently engaged on a human engineering study for the U.S. Air Force.

Mr. Wood is a member of the I.R.E., the Western New York Cooperative Radio Interference Committee, and the American Radio Relay League.

RECENT C. A. L. PUBLICATIONS

The Laboratory invites requests for its unclassified publications as a public service. Supplies of some publications are limited; and those marked with an asterisk may be distributed only within the United States. Please direct your request to the Editor, Research Trends, Cornell Aeronautical Laboratory, Buffalo 21, New York.

"WATCH OUT FOR COMPRESSION LOADS," Yerkovich, L. A.; Reprinted from Product Engineering; December 1957; 4 pages.

Contrary to popular notion, metals are not as strong in compression as they are in tension. Here are commonly overlooked facts on: effect of cold-working, temperature effects, compression creep, sheet properties vs. bar, how compression tests are run.

"A METHOD FOR IMPROVING THE PERFORMANCE OF SHOCK TUBES," Russo, Anthony L. and Hertzberg, Abraham; Reprinted from Jet Propulsion; November 1957; 3 pages.

Modifications of the basic shock tube are considered in order to improve the performance of shock tubes and, in particular, to extend the use of hydrogen to the generation of strong shock waves in air. These modifications are the double-diaphragm shock tube with monatomic buffer gases and the shock tube with an area change at the diaphragm station.

"PHASE-PLANE GRAPHICS — A NEW APPROACH TO TEACHING DYNAMICS," Packer, Leo and Eiss, Norman S.; Reprinted from the American Journal of Physics, Vol. 26, No. 2; February 1958; 12 pages.

Graphical analysis on the phase plane is proposed as a teaching aid for undergraduate courses in mechanics and vibration. The laws of elementary impact are reviewed and a concise phase-plane representation of impact is derived from the impact equations. Advantages of that representation are cited.

"THERMAL DESIGN CHECK POINTS," Welsh, James P.; CAL Report No. HF-1053-D; May 1957; 8 pages.*

A tabulation of factors useful in evaluating the thermal design of an electronic equipment. It is intended as a check-list for the design engineer.

"FINAL REPORT ON THERMAL EVALUATION OF ELECTRONIC ASSEMBLIES," Welsh, James P.; CAL Report No. HF-1053-D-7; 68 pages.*

This evaluation was conducted to determine and improve the thermal performance of assemblies fabricated by automatic production methods. Demonstrated herein are techniques which will aid in the design of reliable electronic assemblies.

"PROPELLER BLADE STALL FLUTTER INVESTIGATION," Part I, Brady, William G.; CAL Report No. SB-950-S-3; January 1958; 110 pages.*

The project described in this report was concerned with an analytical study directed toward the determination of a theory or method for the design of thin high-speed propeller blades which are free from stall flutter. Preliminary data were obtained from seven propeller configurations.

"THE APPLICATION OF THE SHOCK TUBE TO THE STUDY OF THE AEROTHERMAL PROBLEMS OF HIGH-SPEED FLIGHT," Hertzberg, Abraham and Logan, J. G., Jr.; Presented at the Chemical Aeronomy Conference, Yale University, New Haven, Connecticut; June 1956; 12 pages.

The shock tube has been applied to the study of real gas hypersonic flow phenomena, relaxation phenomena and the kinetics of chemical reactions. The kinetics of the reaction $N_2 + O_2 \quad 2NO$ have been studied in a special shock tube and preliminary data are presented on the activation energy and the reaction mechanism in the temperature range between 2000°K and 3000°K.

"BOUNDARY-LAYER TRANSITION AND HEAT TRANSFER IN SHOCK TUBES," Hartunian, R., Russo, A. and Marrone, P.; Presented at the 1958 Heat Transfer and Fluid Mechanics Institute, University of California, Berkeley, California; June 1958; 12 pages.

An experimental study was made of the wall boundary layer in a shock tube operated over a wide range of shock Mach numbers and pressure levels, including those for which dissociation effects exist. Transition points were determined and correlated in terms of boundary-layer displacement thickness. High cooling rates had a stabilizing effect on the laminar boundary layer. The results of the heat transfer measurements substantiate existing theories in both laminar and turbulent flow regimes.

Requests for the following reports will be relayed to the project sponsor.

"CARBON-TITANIUM-BORON STEEL EVALUATION FOR HIGH-TEMPERATURE SERVICE," Salvaggi, John; CAL Report No. KB-1028-M-23; August 1957; 30 pages.

In this evaluation study, the short time properties of the steel were found to vary over the range of chemical composition tested. The variation in properties decreased with time and the long-time properties are about the same for the high and low ends of the composition range. Differences in heat treatment were found to have a much more pronounced effect on properties.

"EVALUATION OF CAST ALLOYS FOR USE AT HIGH TEMPERATURES," Salvaggi, John; CAL Report No. KB-1137-M-4; December 1957; 11 pages.

Austenitic stainless steel compositions containing chromium, nickel, molybdenum and carbon modified by additions of minor quantities of titanium, boron, colombium, and tungsten were cast into test bars using the shell mold process. Several of these compositions displayed excellent high temperature strength properties, accompanied by adequate ductility values.